The prediction of traffic loading at specific sites

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71 heavy goods vehicle (HGV) surveys took place at 52 sites in 7 regions of UK between 1989 and 1991. A random sample of 5456 HGVs were surveyed to provide the data for a review of the current methods used to estimate cumulative traffic loading for road pavement design. New average vehicle wear factors were proposed for each of 8 HGV classes but there were no improvements in accuracy when the data was disaggregated by region or by HGV flow. A new method for estimating cumulative traffic loading was proposed with marginal improvements in accuracy.

1 BACKGROUND

The construction of new and the maintenance of existing road pavements involves significant expenditure each year; for example, during the year 1991/2, approximately £800M was spent specifically on road pavement structures in the United Kingdom (UK) which highlights the scale of expenditure.

A key variable in the structural design of road pavements is an estimation of the cumulative traffic loading which is likely to pass over the pavement during its design life. An error in this estimate will result in a pavement structure which is either over- or under-designed. Highway budgets tend to be finite and any estimate of cumulative traffic loading must be as accurate as possible so that a more optimal allocation of resources can be achieved between competing schemes.

The Traffic Loading Unit (TLU) is a small, but developing centre of excellence within the Transport Operations Research Group (TORG) at the University of Newcastle upon Tyne. The current research programmes have two common aims:

(i) to permit the design and maintenance of road pavements to be a more accurate and reliable process, enabling finite budgets to be allocated more effectively over the highway network; and

(ii) to permit a more equitable approach to the allocation of road track-costs between users of different types of vehicle.

Against this background, the project was aimed specifically at refining the current procedures used to estimate cumulative traffic loading in the UK. The scale of expenditure is such that even small improvements in accuracy can result in significant improvements in the allocation of resources when considered in absolute terms.

2 ESTIMATION OF TRAFFIC LOADING: REVIEW OF PROCEDURES DEVELOPED BY THE UK DEPARTMENT OF TRANSPORT

2.1 LR910 (ref. 1)

This method was based on output from 28 dynamic weighscales at 14 locations on the strategic road network in UK. Three sets of data were included in LR910:

(i) the distribution of commercial traffic between lanes on dual-carriageway roads;

(ii) the estimated changes in the number of axles per commercial vehicle between 1945 and 2005; and

(iii) the estimated changes in the number of standard axles per commercial axle between 1945 and 2005.

Using the above estimations, recommendations were made for the average vehicle wear factors for each of four traffic flow ranges for the period 1979 to 1997.

2.2 LR1132 (ref. 2)

The LR1132 method provided two clear improvements in estimating traffic loading for pavement design when compared to the LR910 method. The rotating census began in 1979 which provided 24-hour annual average daily flows (AADF) at 6250 sites on the motorway, trunk and principal road network.

The second improvement was due to the development of a regression model by Addis and Robinson (ref. 2) to estimate the average commercial vehicle wear factors for specific sites. The model was based on the weighbridge data referred to in Section 2.1 above.

2.3 RR138 (ref. 3)

This is the current method used by DTp and enables traffic loading to be estimated by applying dynamic wear factors to each of seven classes of commercial vehicle. The method is more accurate than and updates that proposed in LR910 and LR1132 but there remains potential for improvement.

3 PROJECT OBJECTIVES

The following objectives were set for this three-year project.

Objective A: to select seven regions of the UK which would be considered, collectively, to represent the characteristics of HGV flow in UK.

Objective B: to select 52 survey sites at locations on the highway networks in the seven chosen regions of the country to represent sites offering a range of traffic flow from 100 to 7000 commercial vehicles per day in each direction.

Objective C: at each survey site to collect data to appraise existing methods of estimating the average vehicle wear factors at specific sites and, if necessary, develop new methods that would allow the DTp and local authorities to match the allocation of resources applied to the construction and maintenance of road pavements of road pavements more effectively over the highway network.

4 CHOICE OF REGIONS AND SITES

The objective was to select seven regions that were distributed throughout the UK and offered a range of population density. This objective had to be balanced with the need for a highway authority to be willing to collaborate particularly with the financial implication that implied.

Once a region had been selected it was necessary to choose a number of sites where HGVs could be weighed safely and accurately. The maximum number of sites in each region depended on the local resources available. Historical classified count data were used to produce a histogram of the number of links with a particular flow range (100 HGVs per day in one direction was taken as the minimum useful flow). The number of links was then weighted by traffic flow and then the histogram was divided into a number of flow bands; the boundaries of these being obtained by calculating the appropriate percentiles (for example to divide into four bands the percentiles of interest would be 25%, 50% and 75%). The next step was to attempt to find a suitable site within each flow range. In some regions there were a number of sites within each band which were suitable and the deciding factor was then to maximise the proportion of the heavier vehicles (ie OGV2), while in others there were some bands with no suitable sites and in these cases a second choice was made in the next band, representing a higher flow.

5 SURVEY METHOD

The RR138 method is based on seven HGV classes. It was decided for this project to use similar classes but to disaggregate the heaviest category into 5- and 6-axle vehicles. The class definitions are given in Table 1.

Table 1. HGV classes

Code	Definition
R2a	2-axle rigid 3.5t>PGW≥7.5t
R2b	2-axle rigid PGW>7.5t
R3	3-axle rigid
R4	4-axle rigid
A3	3-axle articulated (including drawbars)
A4	4-axle articulated (including drawbars)
A5	5-axle articulated (including drawbars)
A6	6-axle articulated (including drawbars)
A5&6	5- and 6-axle articulated (including drawbars)
OGV1	R2a, R2b, R3 and A3
OGV2	R4, A4, A5 and A6

When a site had been chosen the traffic management to enable an HGV to be selected safely at random from the traffic stream was arranged by the highway authority and checked with the police. At some sites, a policeman could direct HGVs into the layby by standing at the entrance, while at other sites mobile police were used to direct the HGV off the road to the weighing site. The importance of obtaining a random sample was impressed upon the police.

Each driver was asked questions about the load he was carrying, its origin and destination and the route he had followed and that he intended to follow. Other details noted were the body-type of the vehicle and the presence of any raised axles. At the same time the following details were taken from the ministry plates:

- the unladen weight,
- the gross vehicle weight,
- the gross train weight, and
- the maximum permitted weights allowed on each axle.

Once this information was collected the vehicle was weighed using one of four different methods:

- A a slow-speed axle weighbridge,
- B1 a set of weighpads to enable all wheels to be weighed simultaneously,
- B2 a set of weighpads with dummy pads for the extra wheels and the vehicle weighed in two stages, or
- C a pair of weighpads set in wooden platforms.

Method A was preferred since it proved to be the quickest and the axle weights were recorded automatically. Method C was the least favoured but it was sometimes necessary if both directions of a route were to be sampled on the same day.

6 ANALYSIS OF DATA

6.1 Site slope

The maximum longitudinal and transverse slopes for each site were considered to be two and five per cent respectively (ref. 4), though a maximum longitudinal slope of one per cent would be preferred. In general, the slopes were well within tolerance and thus the decision was made not to attempt any form of adjustment to the data for the effect of site slope.

6.2 Weighpad calibrations

The weighpads were calibrated at the City of Birmingham Consumer Protection Division at regular intervals.

6.3 Calculation of vehicle wear factor

If $load_i$ is the load on the ith axle and sa is the standard load, usually 8.16t (≡ 80kN) (ref. 5), then the wear factor for an axle (w_{axlei}) is defined as:

$$w_{axle_i} = \frac{load_i^4}{sa^4} \qquad (1)$$

If n is the number of axles on the vehicle then the wear factor for a vehicle (w_{veh}) is defined as:

$$w_{veh} = \sum_{i=1}^{n} w_{axle_i} \qquad (2)$$

Substituting from equation (1) into equation (2) gives:

$$w_{veh} = \sum_{i=1}^{n} \frac{load_i^4}{sa^4} = \frac{1}{sa^4} \sum_{i=1}^{n} load_i^4 \qquad (3)$$

The four methods used to weigh the HGVs produced different data:

A - the axle weighbridge -> axle weights directly;

B1 - set of weighpads -> single set of wheel weights;

B2 - set of weighpads + dummy pads -> two sets of wheel weights; and

C - the two pads set in platforms -> single set of wheel weights.

When weighpads were used the axle load was calculated as the sum of the nearside and offside wheel weights for that axle. If an axle was weighed twice (method B2) then the axle load used in Equation (3) was chosen such that close-coupled axles were weighed simultaneously. For example, if a vehicle with TRRL Code 1.2-111 was weighed with six weighpads and axles 1, 2 and 3 were weighed together [set a] and then axles 3, 4 and 5 were weighed together [set b] the axle loads used would be 1a, 2a, 3b, 4b and 5b.

6.4 Accuracy of different methods of weighing

6.4.1 **Comparison of calculated GVW and documented GVW**

736 (ie 13.5 per cent) of the vehicles had both been weighed previously on their journey and had documents detailing their unladen and gross weights. An assessment of the accuracy of each method of weighing was made by calculating the mean difference between the documented and calculated GVW for the four methods. Weigh method B1 was found to be the most accurate method followed by A, B2 and C.

6.4.2 **Comparison of calculated GVW and the GVW obtained from a whole-vehicle static weighbridge**

The GVW of 314 (ie 5.7 per cent) of the vehicles was obtained from a static whole-vehicle weighbridge within a few minutes of using the weighpads and the value was compared with the calculated GVW. Weigh method B1 was found to be more accurate than B2.

7 RESULTS

7.1 Survey details

71 surveys at 52 sites were carried out on Tuesdays, Wednesdays and Thursdays between September 1989 and October 1991 in Dorset (1980), Cheshire (1990), Strathclyde (1990), Hertfordshire (1991), Tyne & Wear (1991), Cleveland (1991) and Leicestershire (1991) on roads carrying from 106 to 7335 HGVs per 12 hour day.

7.2 Measured average vehicle wear factors

Table 2 gives the number of vehicles sampled and weighed and the mean vehicle wear factor for each HGV class. The RR138 static averages (taken from Table 2 of ref. 3) are shown for comparison. The only significant differences (ie at the 95% confidence level) between the TORG data and the RR138 estimates are the wear factors for the 4-axle articulated (A4) and the 5- and 6-axle articulated (A5&6) vehicles.

Table 2. Mean measured wear factor for each HGV class

HGV class	Cases	Vehicle wear factor (80kN sa) Mean	Std Dev	95% cl	RR138
R2a	858	0.035	0.045	0.003	0.02
R2b	1495	0.478	0.800	0.041	0.46
R3	365	1.201	1.380	0.142	1.30
R4	396	2.130	2.211	0.218	2.30
A3	91	0.495	0.615	0.126	0.50
A4	983	0.984	1.314	0.082	2.00
A5	1065	1.902	1.797	0.108	-
A6	203	1.455	1.241	0.171	-
A5&6	1268	1.831	1.727	0.095	2.70
OGV1	2809	0.437	0.852	0.032	-
OGV2	2647	1.561	1.734	0.066	-

7.3 Site average wear factors and correlation with flow

The site average wear factor was correlated with the corresponding 12 hour HGV flow at that site, for each region and for each vehicle class. The slope of only six of the 79 regression lines derived was found to be significantly different from zero at the 95% level.

7.4 Site average wear factors and correlation with proportion of empty vehicles

It was thought that one indicator of the site average wear factor for each of the vehicle categories might be the percentage of empty vehicles in each class at that site. If this was to be the basis for an estimation method, then only those empty vehicles that could be seen to be empty could be recorded during a manual classified count. Therefore, for each vehicle category at each site, the numbers, and hence the percentages, of empty (defined as ≤ 10% lading) vehicles, with bodytypes that would permit visual inspection (for example flat open loadbed, bulk carrier, car transporter), were calculated. Draw-bar trailers were excluded from the analysis because of the difficulty in assigning to them an unladen weight (required in the calculation of lading). The data was put into five per cent empty bands and plotted against average wear factor for that vehicle category calculated from those particular sites. The best straight line through the points was found by calculating the product of correlation, or r^2 value, for:

(i) linear (wear factor) against linear (%empty),
(ii) log (wear factor) against linear (%empty),
(iii) log (wear factor) against log (%empty),

and then taking the maximum value of r^2. Table 3 shows the result of the regressions.

Table 3. Best-fit straight lines

HGV class	Model-structure	r^2	slope (a)	intercept (b)
R2a	lin/lin	0.57	-0.0004	0.0368
R2b	log/lin	0.61	-0.0091	-0.2777
R3	lin/lin	0.50	-0.0161	1.5401
R4	lin/lin	0.90	-0.0322	3.1380
A3	log/lin	0.84	-0.0084	-0.1185
A4	log/lin	0.72	-0.0072	0.0529
A5	lin/lin	0.78	-0.0173	2.0333
A6	log/log	0.87	-0.9843	1.1227

Thus, in the prediction of wear factor (w_i) from the percentage of 'visibly' empty vehicles the following four equations were used:

(i)

$$\text{linear/linear:} \quad w_i = a.empty + b \qquad (4)$$

(ii)

$$\text{log/linear:} \quad w_i = 10^{(a.empty+b)} \qquad (5)$$

(iii)

$$\text{log/log:} \quad (\text{empty}) \neq 0 \quad w_i = 10^{(a.\log(empty)+b)} \qquad (6)$$

$$\text{log/log:} \quad (\text{empty}) = 0 \quad w_i = 1.49 \qquad (7)$$

7.5 Estimates of average wear factor

7.5.1 **DTp methods**

Both the LR910 and LR1132 methods require a value for AADF when estimating the average vehicle wear factor. These AADF values were obtained by using a figure for the 12-hour count, between the hours of 7am and 7pm, and multiplying by one expansion factor to convert to 16 hours and then another expansion factor to convert to 24 hours. These expansion factors were supplied by the highway authorities. If the count was between 6am and 6pm, the 7am to 7pm count was derived by reducing the former by 1.4% (TRRL figure).

The LR910 and LR1132 methods give wear factors that are based on dynamic weighscale data and thus have to be reduced to enable a direct comparison to be made with wear factors from static weighings. RR138 suggested a factor of 1.3, but an analysis of more recent data in CR122 (ref. 6) indicated an average ratio for dynamic:static wear factor of 1.45 ± 0.12. This was the factor used to reduce the LR910 and LR1132 estimates to represent static factors.

The RR138 method requires the proportion of vehicles in each HGV category to estimate the average wear factor for each site. At each site two estimates using RR138 wear factors were possible: (a) the proportions from the total flow and (b) those from the sample.

The four DTp estimates of wear factor are plotted against HGV flow in Fig. 1, with the measured values being included for comparison.

The ratio of estimated to measured wear factor have been calculated for each site and are summarised in Table 4.

Table 4. Ratio of DTp estimated to measured wear factor

DTp method	Cases	Statistic Min	Max	Mean	Std Dev
LR910	67	0.31	4.74	1.49	0.83
LR1132	67	0.31	4.48	1.48	0.78
RR138a	68	0.66	3.99	1.52	0.68
RR138b	71	0.82	3.74	1.52	0.56

The correlation between the measured and each estimated wear factor was calculated and the results are given in Table 5.

Table 5. Correlation between measured and DTp estimated wear factor

DTp method	Cases	r^2	slope	intercept
LR910	67	0.33	0.48	0.38
LR1132	67	0.35	0.55	0.30
RR138a	68	0.50	1.08	-0.36
RR138b	71	0.58	0.86	-0.15

7.5.2 **TORG methods**

The approach in all the TORG methods has been based on that in RR138. The wear factor for a set of vehicles (w_{SET}) made up of n categories was calculated by combining the vehicle wear factor for the different categories. If w_i is the vehicle wear factor for the i th vehicle category and p_i is the proportion of vehicles in the i th vehicle category, then:

$$w_{SET} = \sum_{i=1}^{n} p_i w_i \qquad (8)$$

Table 6 identifies the source of w_i and the size of n for the different TORG estimates. Table 7 shows some statistics of the ratio of estimated to measured wear factor and table 8 gives the results of correlation between the measured and estimated wear factors.

8. SIGNIFICANCE OF RESULTS FOR PAVEMENT DESIGN

The significance, or otherwise, of the different estimation methods may be demonstrated by designing a pavement using the estimated wear factors and comparing these design thicknesses with those derived using the measured wear factor. Since weighscale results have provided

Table 6. Source of w_i and n

TORG method	w_i	n*
1	All regions	8
2	All regions	2
3	Regions	8
4	Regions	2
5	All regions + flow	8
6	All regions + flow	2
7	Regions + flow	8
8	Regions + flow	2
9	Per cent empty	8

* If n = 8 then the categories are R2a, R2b, R3, R4, A3, A4, A5 and A6
If n = 2 then the categories are OGV1 and OGV2 only

Table 7. Ratio of TORG estimated to measured wear factor

TORG method	Cases	Statistic Min	Max	Mean	Std Dev
1	71	0.58	3.01	1.12	0.43
2	71	0.53	3.72	1.16	0.54
3	71	0.56	2.82	1.10	0.39
4	71	0.50	3.51	1.12	0.51
5	71	0.57	2.78	1.10	0.40
6	71	0.52	3.65	1.18	0.52
7	71	0.59	2.82	1.10	0.38
8	71	0.52	3.51	1.11	0.50
9	71	0.57	3.60	1.08	0.33

Table 8. Correlation between measured and TORG estimated wear factor

TORG method	Cases	r^2	slope	intercept
1	71	0.65	1.51	-0.45
2	71	0.49	1.53	-0.47
3	71	0.68	1.25	-0.21
4	71	0.56	1.20	-0.16
5	71	0.64	1.37	-0.31
6	71	0.48	1.16	-0.15
7	71	0.70	1.22	-0.19
8	71	0.54	1.35	-0.27
9	71	0.78	1.26	-0.23

the traffic inputs used in developing designs for new roads found in LR1132, vehicle wear factors derived from static axle weights should be converted to equivalent weighscale values by multiplying by 1.453. The total number of HGVs using the nearside lane over the design life (T_n) was calculated for each site using Equation B1 of LR1132, assuming a three per cent per annum growth rate and a 20 year design life. The cumulative traffic loading for the pavement was then calculated by multiplying T_n by the wear factor (and multiplying by 1.453 for the RR138 and TORG estimates). The thickness of the bound layers was then taken from the design curve given in Figure 3 of LR1132 (note: for traffic loading between 80 and 200 Msa the graph had to be extrapolated).

The difference in design thickness was calculated for each of 67 sites where flow data were available. Table 9 gives some statistics for this difference for each estimation method. The number of sites where the difference in design

Table 9. Design thickness difference (ie estimated-measured)

Estimation method	Average mm	Std Dev mm	Sites with difference ≥ 10mm
LR910	13.52	22.72	46
LR1132	13.48	21.39	44
RR138a	15.22	16.95	46
RR138b	16.32	14.74	47
TORG1	1.46	15.29	33
TORG2	1.44	18.03	41
TORG3	1.33	14.32	33
TORG4	0.10	17.78	40
TORG5	0.97	14.74	33
TORG6	2.91	17.23	38
TORG7	1.35	13.93	31
TORG8	0.14	17.26	39
TORG9	1.05	12.06	28

thickness was at least 10 mm (ie considered significant in construction terms) is given also in the table.

9 GENERAL CONCLUSIONS

This project has involved extensive data-collection, followed by detailed statistical analysis. There were four main general conclusions that could be drawn from the results, though many more detailed conclusions can be found by referring to sections 7 and 8.

(i) There was no significant benefit in developing and applying average vehicle wear factors for specific regions of UK or specific ranges of commercial vehicle flow. There was significant benefit in developing and applying average vehicle wear factors for specific classes of HGV. This was not the case for the sub-sets OGV1 and OGV2, where too much sensitivity was sacrificed.

(ii) Table 4 confirms that the three methods used by DTp to estimate average vehicle wear factors for pavement design (i.e. LR910, LR1132 and RR138) overestimated structural pavement wear.

(iii) Table 7 confirms that the nine TORG methods overestimated structural pavement wear by an average of between 8 per cent and 18 per cent, reflecting the fact that HGVs have become, on average, less damaging in recent years.

(iv) The TORG 9 method produced the best estimate of cumulative traffic loading for pavement design. The number of sites where the pavement depths differed by more than 10 mm when the pavement depth was based on the measured compared to the estimated traffic loading, was reduced from a figure of 68 sites when the current RR138 method was used compared to 28 sites when the TORG 9 method was used. However, the TORG 9 method was considerably more complex than the TORG 1 method where the comparable figure was reduced to 33 sites. It may be sufficiently accurate to recommend the TORG 1 method which represents in every respect an updated version of the current RR138 method.

10 FURTHER WORK

In recent years, a clearer understanding has been formed of the mechanism of the dynamic loading applied to road pavements. These new findings need to be developed into a method for estimating cumulative traffic loading for road pavement design and the allocation of road track costs.

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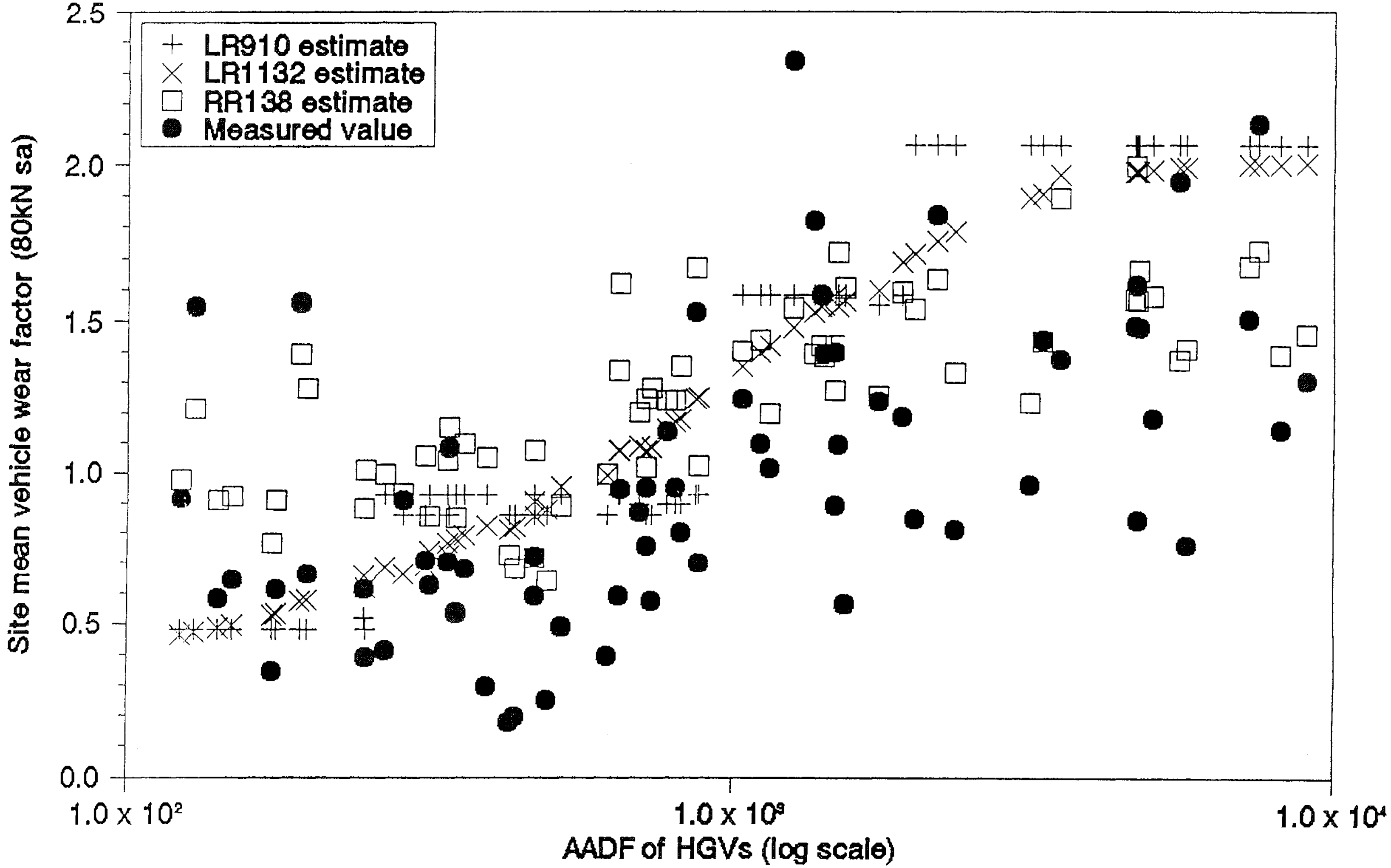

Fig. 1. DTp estimates for vehicle wear factor